The Photon:
Spotlight

On Alumnus Philip Johnson

Alumnus Philip Johnson is an alum three times over and a physics jack-of-two trades! Check out how he got mixed up with the Dynamical Systems and Accelerator Theory (DSAT) and Superconducting Quantum Computing (SQC) groups below!

by Philip Johnson, Class of 1991, 1994 and 1999

Phil at a quantum beam physics conference on the island of Capri off the Italian coast last fall. Great place for a conference!

What do quantum beams and quantum computers have in common? They are both examples of where the frontier of technology is entering the quantum domain. Of course, quantum physics plays a crucial role in modern technology (e.g. transistors, lasers); however, these present day technologies just scratch the surface of what may be possible in quantum mechanics. Particularly fascinating issues with both conceptual and practical significance include the following: How do we understand the appearance of a classical world from a quantum one; how do well-established classical disciplines fit into a deeper quantum description of nature; what is possible (technologically) in quantum physics?

As a postdoc with the Dynamical Systems and Accelerator Theory (DSAT) and Superconducting Quantum Computing (SQC) groups, I get to think about these issues every day. The diversity of projects with which I am involved is probably not the norm for a postdoc. This is challenging since, despite some common themes, in practice, I find myself working simultaneously on a number of different projects. The reward is that I am constantly learning new things, which is why I went into physics in the first place.

I began my physics career at Maryland as an undergraduate. I finished still wanting to know more, so naturally, I went to graduate school. Maryland was a great choice because it is strong in so many different areas, including cosmology and general relativity, which I hoped to study. It was also important to me to stay close to my family and friends in this area.

As a graduate student, I enjoyed working on different subjects. This has a downside because I definitely made slower progress by not focusing on just one project at a time. Despite being a theorist, I also had the unusual opportunity of teaching GradLab for a number of years, and I sometimes find

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On Chaos and Non-Linear Dynamics

The Science of Flowing Sand

by Wolfgang Losert *(http://www.ipr.umd.edu/granular)*
Assistant Professor, UM Physics, the Institute of Plasma Research and the Institute of Physical Science and Technology

We encounter granular materials such as sand, coal or wheat everywhere in nature and industry. Surprisingly, many fundamental properties of granular matter are still poorly understood. Even though the material properties of individual grains are well known, an assembly of many particles can behave in unexpected ways. The granular "consistency" has obvious importance for sand dune formation, avalanching, rockslides, or for the building of sandcastles (see figure 1). The images illustrate that granular matter can have strength like a solid, flow like a liquid, or have both properties[1]. (For example, a sand dune can support the weight of a person, yet the surface exhibits ripples just like a liquid.)

Solid-like (Sandcastle)
photographs courtesy Sandy Feet

Fluid-like (Avalanche)
photographs courtesy Richard Iverson, U.S. Geological Survey

In-Between (Sand dune with surface ripples)
photographs courtesy Philip Greenspun

Figure 1: *Properties of granular matter*

Materials consisting of ensembles of many grains also occur in unexpected places: The material in fault zones between tectonic plates is granular, due to the grinding of rocks when tectonic plates slide.The way that granular consistency influences the sliding of tectonic plates, i.e. earthquakes, is an active area of research.

The term granular matter generally refers to systems of particles (or grains in this case) that are so large (larger than ~ 1 micron) that heat is not enough to move the particles around. In fact, at thermal equilibrium, (or basically, room temperature) granular matter is (almost) at rest and resembles a solid, where atoms or molecules are locked in place. Extra energy, created through shaking, for example, is required to bring the system of grains into motion and away from its equilibrium state. In fact, since the system of sand's equilibrium state is solid-like, the fluid-like state of sand may be considered far from equilibrium. Many interesting phenomena, such as avalanching, involve the motion of grains. So how can such far-from-equilibrium behavior be described?

Since granular flows are directly observable, a detailed description of experimentally observed flow properties is straightforward: Measure the flow property of interest as a function of the properties of individual grains, and describe the results (e.g. by some functional form). This yields predictive results, if the same grains are used under the same flow conditions.

Since the energy of moving particles is larger than thermal energy, kinetic energy gets lost into heat during each collision, i.e. the collisions are inelastic. So energy has to be continuously added to sustain a granular flow - for avalanches energy is fed into the granular material through gravity. In the lab, energy is supplied to the granular material through vertical shaking of grains, or shearing of grains, between two concentric cylinders, as shown in figure 2. When particles are sheared between two cylinders, the grains move rapidly close to the rotating cylinder, and most of the energy is lost in collisions in the first few layers close to the moving cylinder. This is shown in the figure 2 inset, where the instantaneous velocity of individual particles on the surface, obtained through particle tracking, is shown as lines on individual particles (the particles actually touch, but only the center of each particle is shown here). The rotating inner cylinder is on the left in this image.

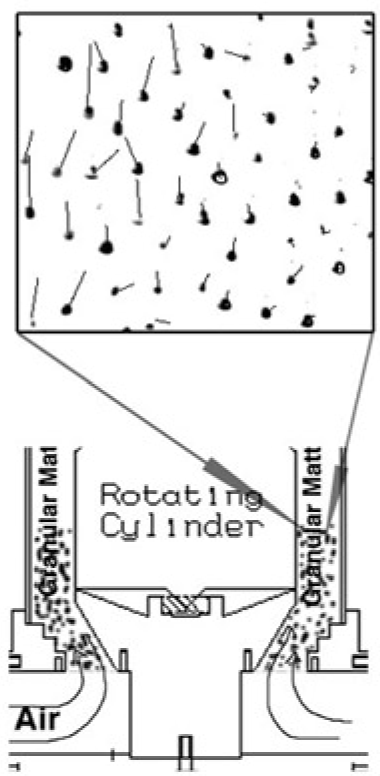
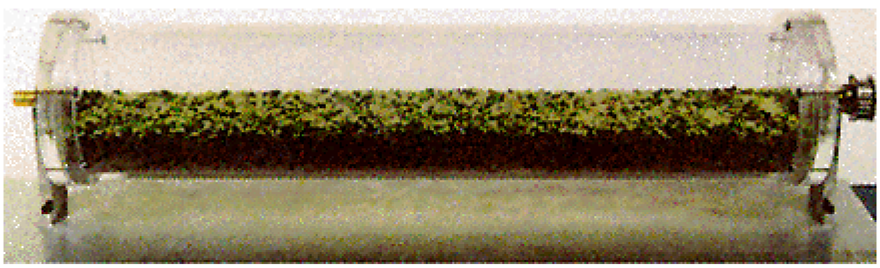


Figure 2: *Shearcell with rotating inner cylinder to study granular flow.* **Inset:** *Motion of particles during granular flow, imaged from above, with the inner cylinder to the left.*

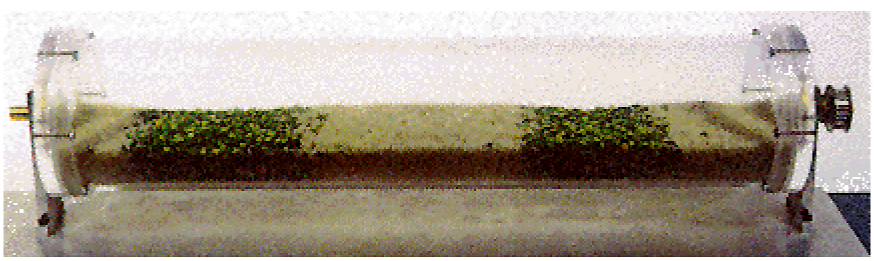
The next step is crucial to make such experiments worthwhile: drawing general conclusions with the power to predict other granular flows with new and perhaps unexpected flow properties.

General conclusions may at first sight be difficult to draw, since individual grains can be characterized by many parameters. The friction between grains, inelasticity, particle shape, deformability, or surface roughness all could play a role in the flow properties. For the simplest model we treat all particles as balls that collide with each other, but we ignore all specific properties, except for the fact that particles lose some energy in each collision. This description has shown promising results recently: Such a simple model correctly describes the motion of grains in a shearflow of figure 2. It also correctly predicts the forces necessary to create the flow. The key to finding an appropriate model was to describe the state of grains far from the cylinder as an almost glass-like state. The jamming of grains in this region exhibits surprising similarities to the behavior of supercooled liquids close to the glass transition [2].

While we can explain grandular flow by paralleling it to ordinary fluids or glasses, other very important granular properties appear to possess no simple analogies. When a cylinder with a mixture of rice and peas is rotated horizontally, the material separates into alternating bands of rice and peas, as shown in figure 3. This behavior occurs frequently: grains separate by size or weight under vibration or during flow, but the reasons for this separation are hard to discern. Mixing of grains in industry is in fact an art as much as a science, as discussed in a recent review article in Physics Today that describes the enormous range of still largely unexplained mixing effects in granular materials[3].



Initial Mixture of Uncooked Rice and Split Peas



After Rotation About Horizontal Axis at 15 rpm for 2 hours

Figure 3: *Separation of a mixture of rice and peas in a slowly rotating cylinder (J. Kakalios group).*

This example illustrates that there is a long way to go towards a general description of the far from equilibrium dynamics of granular matter. The potential connection between granular jamming and supercooled liquids may help us learn general principles of the far from equilibrium dynamics of granular matter, which is an easy to observe system. Experience shows that we can also hope to observe other unexpected properties of sand.

Check out Dr. Losert's website at http://www.ipr.umd.edu/granular.

[1]Clement, E., 1999. Rheology of granular media. *Curr. Opinion Coll. & Int. Sci.* 4: 294-299.
[2]W. Losert, L. Bocquet, T.C. Lubensky, and J.P. Gollub, "Particle dynamics in sheared granular matter," *Phys. Rev. Lett* 85, 1428 (2000)
[3]T. Shinbrot and F.J. Muzzio, "Nonequilibrium patterns in granular mixing and segregation," *Physics Today*, pg. 25, March 2000.

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myself regretting not becoming an experimentalist after my GradLab experiences. I have always enjoyed building things, or trying to fix them, and after a long day of calculating, I am sometimes especially tempted to trade my pencil for a soldering iron or volt-meter.

My wife, Jennifer, and I at the Oracle in Delphi. An important Quantum Computing Application called Grover's Algorithm requires building a quantum Oracle, which is a lot harder than visiting the original in Greece.

My wife discovered this to her dismay a few weeks ago when I took apart my laptop while trying to fix it and found I wasn't sure how to get it back together again. Fortunately, it is working now even if it isn't looking very pretty.

Getting a postdoc here was serendipitous. My wife, Jennifer, and I did not want to leave the area, but if one wants to stay in academics, this is often not an option. Fortunately, while I was finishing my dissertation I learned that **Profs. Bob Anderson**, **Chris Lobb**, **Fred Wellstood**, and **Alex Dragt** were starting a collaboration on quantum computing. I had been interested in this area for the last few years, so I jumped at the chance to work with them.

Quantum computing has the goal of controlling the quantum world in a way that was never seriously entertained before. Indeed, it was not that long ago when computer scientists were speculating that the famous Heisenberg uncertainty principle (quantum uncertainty) fundamentally limits how small computers can ultimately be made before intrinsic randomness makes them useless. Surprisingly, the pioneers of quantum computing discovered that quantum uncertainty may not necessarily limit computation. Instead, it appears that quantum computers with powers dwarfing so-called classical computers may be possible, if only we achieve a sufficient understanding of quantum systems. What is more, the foundations underlying quantum computing have the potential to unify physics, information theory, and computer science in a profound way. The challenge is that the technology needed to build quantum computers goes far beyond anything we have achieved up to now.

One of the most exciting aspects of my work with the SQC group is that we are not only trying to understand quantum computers, we are trying to build one! What is more, because we are trying to engineer macroscopic quantum superconducting devices, the physics involved goes to some of the deepest questions in quantum mechanics. For example, one such question is how (and when) classical macroscopic properties emerge, and whether macroscopic quantum states can be produced (e.g., the infamous Schrodinger's cat).

In another direction, **Prof. Alex Dragt** and I are trying to better understand the quantum physics of motion. **Prof. Dragt** has been a leader in the classical theory of nonlinear particle dynamics using sophisticated mathematics to model particle motion in accelerators. When one considers that billions of dollars are spent on machines that must accelerate particles that cover thousands of miles before colliding head on, one realizes that this field is also pushing against the state-of-the-art in technological control. Up to now, particle motion in these hugely complex devices has been modeled primarily with classical physics, which is a challenging enough problem since these a nonlinear systems are subject to chaos. But ultimately, particle motion should be understood from quantum theory, and it turns out that there are many unanswered questions in this regard. Traditional quantum-mechanical scattering theory is great at predicting what happens when particles collide, but the questions that we are asking are of another type entirely.

Unexpectedly, there is a connection between these kinds of questions, and my thesis work with **Professor Bei-Lok Hu**. The subject of my dissertation concerned how particles move through space and time in quantum physics. The original motivation for this research direction is a surprising parallel between accelerated particle motion in quantum fields and black hole physics, and even quantum cosmology. What I didn't know when I was doing my graduate research was that there is a growing field of quantum beam physics that potentially ties this work to many other areas of exploration, including accelerator physics.

Another significant connection between quantum computers, quantum beams physics, and my thesis work arises from the process of decoherence. Decoherence is important in quantum cosmology where researchers have tried to understand how a classically behaving spacetime might emerge naturally from quantum gravity.

In my thesis work on particle motion, decoherence was important because the very idea of smooth, well-defined motion is classical, and so one must try to explain how this property emerges from the quantum theory of particles. In the study of decoherence, a set of particularly influential papers by Caldiera and Leggett applied methods similar to those I used in my thesis work to the analysis of superconducting interference devices (e.g. SQUIDS). Decoherence is now seen to be one of the fundamental obstacles to producing a quantum computer whose qbits are of any design (SQUIDS, Josephson junction, atoms, electrons, photons, molecules,…). Hence, this field is naturally multidisciplinary, and it gives me a chance to learn new science everyday.

One thing I do miss is teaching. Being a TA was a very rewarding part of my graduate career, and I hope that before long I will find myself in a position to teach again. What the future holds is uncertain, but I have at least achieved my first goal of finding fascinating and challenging work.

• See Phil's profile

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